STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 16-66

WEATHER MODIFICATION OPERATIONS IN CALIFORNIA

OCTOBER 1, 1965–SEPTEMBER 30, 1966

AUGUST 1967

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

Cover Photo:

Precipitation from a small cumulus cloud over the Southern Sierra Range. Clouds such as this are studied in weather modification research programs.

Photo courtesy of Atmospherics Incorporated.

FOREWORD

The issuance in 1966 of reports by the National Academy of Sciences and the National Science Foundation marked a turning point in the prevailing opinion of scientists on the subject of weather modification. In contrast to previous attitudes of skepticism, there now appears to be a consensus that weather modification is a subject of prime importance and one for legitimate scientific inquiry and engineering development. It has been demonstrated that, using existing knowledge and presently available technology, physical changes in clouds can be produced artificially.

Weather modification operations in California are governed by Chapter 4, Division 1, Sections 400 through 415 of the Water Code. These Water Code Sections prescribe procedures for licensing contractors and for initiating and reporting a project. The sections also describe special cases and indicate penalties for violation of the statute. The Department of Water Resources administers the Water Code provisions governing weather modification operations in California.

This bulletin, the eleventh in a continuing series, presents a description of weather modification projects and evaluation techniques in California, according to data in notices of intention, project completion reports, and project evaluation reports submitted to the Department under the Water Code requirements.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
State of California
June 30, 1967

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ABSTRACT

Eight California licensees conducted 11 cloud-seeding projects during the 1965-66 water year. The projects were conducted mainly to increase surface storage for municipal and irrigation uses, for use in recreational facilities, and for use in hydroelectric installations. Additional purposes were ground water storage and applied research. Seven project target areas were in central California, three in southern California, and one in the northern Sierra Nevada.

Cloud seeding hours logged (not including electric discharge method) were: 13,283 from ground, 246 from aircraft. Eight licensees used silver iodide, dispersed from ground-based generators or aircraft, as a nucleation agent. In addition to silver iodide, one licensee dispersed 213 pounds of dry ice. One licensee used the electric discharge method, in which ions discharged from stainless steel wires act as a nucleation agent. This unit was operated during 323 days of the 1965-66 season.

ACKNOWLEDGMENTS

The Water Rights Engineering Section wishes to thank the weather modification licensees of California for their cooperation in supplying information on their cloud-seeding projects, particularly North American Weather Consultants, Vista Irrigation District, and Atmospherics Incorporated for supplying illustrations.

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The Resources Agency
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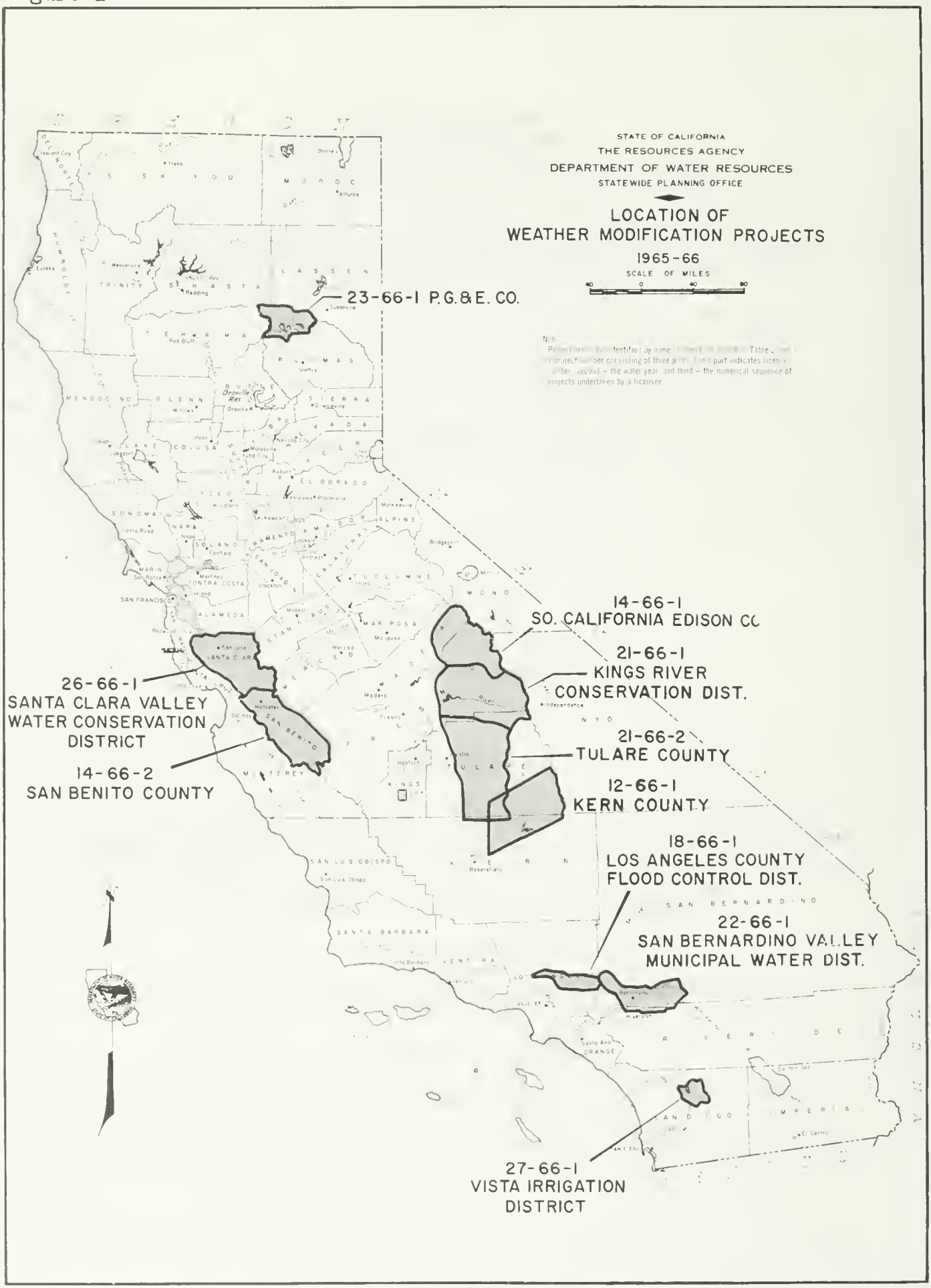
Figure 1


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
STATEWIDE PLANNING OFFICE
LOCATION OF
WEATHER MODIFICATION PROJECTS
1965-66
SCALE OF MILES
23-66-1 P.G.&E. CO.
14-66-1
SO. CALIFORNIA EDISON CO
21-66-1
KINGS RIVER
CONSERVATION DIST.
21-66-2
TULARE COUNTY
12-66-1
KERN COUNTY
26-66-1
SANTA CLARA VALLEY
WATER CONSERVATION
DISTRICT
14-66-2
SAN BENITO COUNTY
18-66-1
LOS ANGELES COUNTY
FLOOD CONTROL DIST.
22-66-1
SAN BERNARDINO VALLEY
MUNICIPAL WATER DIST.
27-66-1
VISTA IRRIGATION
DISTRICT

CHAPTER I. SUMMARY OF OPERATIONS

During the 1965-66 water year (October 1965 - September 1966), eight licensees conducted 11 weather modification projects. Ten projects were conducted to increase precipitation for surface storage. One project, Project Orographic Cumulus, was an applied research effort.

The purpose of the Santa Clara Valley Cloud Seeding Project and the San Benito County Weather Modification Project was to increase ground water storage as well as surface storage. In addition to increasing surface storage for municipal use and irrigation, the Upper Santa Ana River Watershed Weather Modification Project also benefited recreational facilities in the San Bernardino National Forest. The Kings River Weather Modification Program, the Tulare County Weather Modification Project, and the Artificial Modification of Atmospheric Space Charge at Warner Ranch, although conducted to increase surface storage in reservoirs, included research efforts as well. Two weather modification projects -- the Upper San Joaquin River Basin Weather Modification Project and the Lake Almanor Cloud Seeding Project -- were conducted to increase runoff upstream from hydroelectric installations.

Most of the 11 weather modification projects were conducted in central or southern California. Seven projects were conducted in central California and three in southern California. One project, the Lake Almanor Cloud Seeding Project, was conducted in northern California. Locations of weather modification projects in California are shown on Figure 1.

The period of most extensive weather modification operations comprised the months November through May. However, one licensee, North American Weather Consultants of California, extended generator operations of its Upper San Joaquin River Basin Weather Modification Project through June, July, and August. Project Orographic Cumulus, conducted by Atmospherics Incorporated, commenced in June and continued through September. In addition, Vista Irrigation District conducted operations for its Artificial Modification of Atmospheric Space Charge at Warner Ranch during each month of the water year. Some weather modification operations thus occurred during every month of the 1965-66 season. Days of cloud seeding for each project are shown in calendar form on Figure 5 (pages 16 and 17).

Heaviest seeding, according to monthly totals of days of seeding -- excluding the project of Vista Irrigation District, in which continuous operation was attempted -- took place in December, February, and March. There were 17 days of seeding in December, 16 in February, and 15 in March. Totals of over 10 days of seeding were recorded for November, January, June, and August. Lightest seeding occurred in October and September, having 2 and 3 days, respectively.

A total of 122 days of seeding -- excluding the project of Vista Irrigation District, which was operated on 323 days -- occurred during the 1965-66 season. Seeding from ground-based equipment occurred on 102 recorded days of seeding. Seeding from aircraft occurred on 64 days. Total days of cloud seeding per month, together with monthly totals for ground-based equipment and for aircraft, are shown on Figure 2.

A total of 13,283 hours of seeding from ground-based equipment -- excluding operations of Vista Irrigation District, which were logged by days -- occurred during the 1965-66 season. For Vista Irrigation District's Artificial Modification of Atmospheric Space Charge at Warner Ranch, the electric discharge method was used. Ground-based equipment used by other licensees comprised generators dispersing silver iodide.

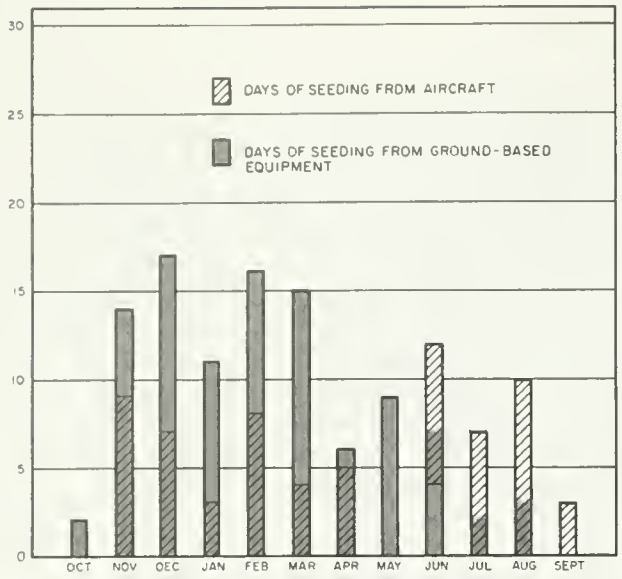


Figure 2. TOTAL DAYS OF CLOUD SEEDING PER MONTH IN CALIFORNIA OCTOBER 1, 1965 - SEPTEMBER 30, 1966

NOTE A TOTAL OF 122 DAYS OF SEEDING OCCURRED DURING THE 1965-66 SEASON - EXCLUDING THE PROJECT OF VISTA IRRIGATION DISTRICT, WHICH WAS OPERATED ON 323 DAYS

Seeding from ground-based equipment occurred during every month of the 1965-66 season except September. Heaviest seeding from ground-based equipment according to monthly totals of hours of seeding occurred during November and December. There were 3,771 hours of seeding in November and 3,625 in December. Substantial monthly totals of hours of seeding were logged in January, February, and March when ground-based equipment was operated for 1,533 hours, 2,211 hours, and 787 hours, respectively. In all other months, about 500 hours or less per month of seeding from ground-based equipment occurred. Total hours of cloud-seeding per month from ground-based equipment are shown on Figure 3.

A total of 246 hours of seeding from aircraft was logged during the 1965-66 season. Seeding from aircraft occurred all months of the season except October and May. The heaviest seeding from aircraft, according to monthly totals of hours of seeding, occurred during November and February, when 58.7 hours and 49.1 hours, respectively, were logged. March and September had totals of less than 10 hours each. All other months in which seeding from aircraft occurred had totals of 33.9 to 12.9 hours. Total hours of cloud seeding per month from aircraft are shown on Figure 4.

Eight licensees used silver iodide, dispersed from ground-based generators, aircraft, or pyrotechnic fusees used from aircraft, as a nucleation agent. In addition to silver iodide, one of these licensees, Atmospherics Incorporated, dispersed 213 pounds of dry ice (CO_2 crystals) during its Project Orographic Cumulus. In contrast, one licensee, Vista Irrigation District, used the electric discharge method, in which ions discharged from stainless steel wires act as a nucleation agent.

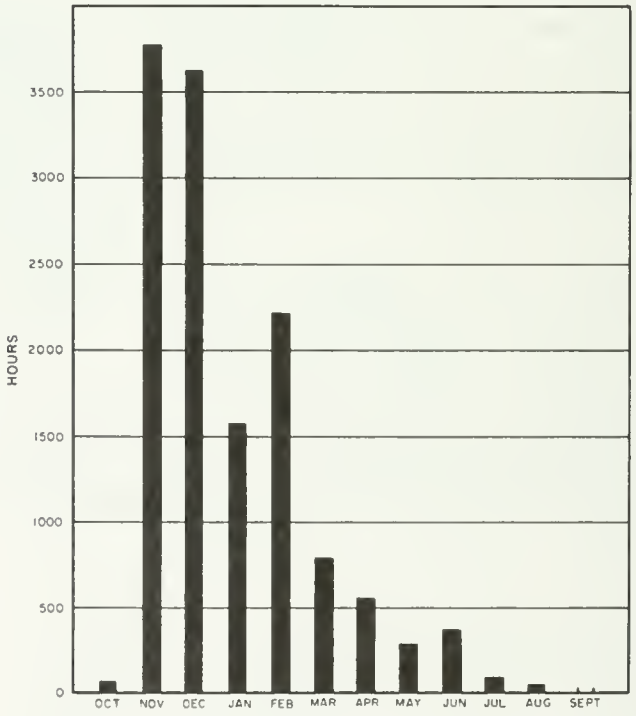


Figure 3. TOTAL HOURS OF CLOUD SEEDING PER MONTH FROM GROUND-BASED EQUIPMENT OCTOBER 1, 1965 - SEPTEMBER 30, 1966

NOTE THESE HOURS WERE LOGGED DURING 102 DAYS OF SEEDING FROM GROUND-BASED EQUIPMENT - EXCLUDING THE PROJECT OF VISTA IRRIGATION DISTRICT, WHICH WAS ATTEMPTED TO OPERATE CONTINUOUSLY

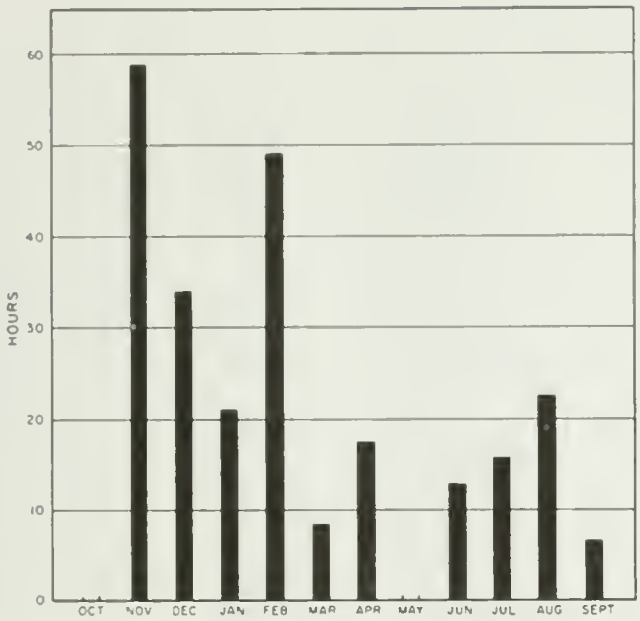


Figure 4 TOTAL HOURS OF CLOUD SEEDING PER MONTH FROM AIRCRAFT OCTOBER 1, 1965 - SEPTEMBER 30, 1966

NOTE THESE HOURS WERE LOGGED DURING 64 DAYS OF SEEDING FROM AIRCRAFT

A list of weather modification licensees is given in Table 1. Weather modification projects are summarized in Table 2, and weather modification project operations are summarized in Table 3.

State and Federal provisions governing weather modification operations may be found in Department of Water Resources Bulletin No. 16-65.

Since weather modification operations to some extent reflect precipitation patterns, statewide precipitation for the 1965-66 water year (October 1965 through September 1966) is summarized in Appendix A.

TABLE 1. ACTIVE WEATHER MODIFICATION LICENSES DURING OCTOBER 1965 THROUGH SEPTEMBER 1966

License Number and Licensee

1 North American Weather Consultants
Santa Barbara Municipal Airport
Goleta, California 93017

5 Water Resources Development Corporation
611 S. Palm Canyon Drive
Suite 16
Palm Springs, California 92262

6 Weather Modification Company
San Jose Municipal Airport
San Jose, California 95110

12 Precipitation Control Company of California
105 Pierce Street
Taft, California 93268

14 North American Weather Consultants of California
Santa Barbara Municipal Airport
Goleta, California 93017

18 Los Angeles County Flood Control District
P. O. Box 2418, Terminal Annex
Los Angeles, California 90033

21 Atmospherics Incorporated
3435 E. Pontiac Way
Fresno, California 93726

22 San Bernardino Valley Municipal Water District
355 North D Street
P. O. Box 1144
San Bernardino, California 92402

23 Pacific Gas and Electric Company
245 Market Street
San Francisco, California 94105

24 International Weather Control, Inc.
40 West First Street
Suite 104
Reno, Nevada 89501

25 K. R. C. Service Corporation
2956 C Street
San Diego, California 92102

26 Santa Clara Valley Water Conservation District
15420 Almaden Road
San Jose, California 95118

27 Vista Irrigation District
P. O. Box 1088
Vista, California 92083

TABLE 2. SUMMARY OF WEATHER MODIFICATION PROJECTS IN CALIFORNIA
OCTOBER 1, 1965 - SEPTEMBER 30, 1966

Project Number*	Licensee	Target Area	Period of Seeding	Purpose of Precipitation Increase
12-66-1	Precipitation Control Company of California	Upper Kern River Watershed	Nov. 13, 1965 Apr. 18, 1966	Surface Storage
14-66-1	North American Weather Consultants of California	Upper San Joaquin River Basin	Oct. 14, 1965 Sep. 16, 1966	Storage in hydroelectric installations
14-66-2	North American Weather Consultants of California	San Benito County	Dec. 24, 1965 May 9, 1966	Surface and ground water storage
18-66-1	Los Angeles County Flood Control District	Drainage areas tributary to District's reservoirs	Nov. 13, 1965 May 10, 1966	Surface storage
21-66-1	Atmospherics Incorporated	Kings River Watershed above Pine Flat Dam	Nov. 13, 1965 Apr. 21, 1966	Surface storage
21-66-2	Atmospherics Incorporated	Tulare County	Nov. 12, 1965 Apr. 18, 1966	Surface storage and research
21-66-3	Atmospherics Incorporated	Southern Sierra Mountains	June 4, 1966 Sep. 23, 1966	Applied research on orographic cumulus clouds
22-66-1	San Bernardino Valley Municipal Water District	Upper Santa Ana River Watershed	Nov. 23, 1965 Feb. 2, 1966	Surface storage and recreation
23-66-1	Pacific Gas and Electric Company	Watersheds of Mountain Meadows and Butt Valley Reservoirs and Lake Almanor	Nov. 24, 1965 May 14, 1966	Storage in hydroelectric installations
26-66-1	Santa Clara Valley Water Conservation District	Santa Clara County	Nov. 12, 1965 Mar. 19, 1966	Surface and ground water storage
27-66-1	Vista Irrigation District	Lake Henshaw Watershed, San Diego County	Oct. 1, 1965 Sep. 30, 1966	Surface storage and research

*First number indicates license number; second, the water year; third, numerical sequence of projects undertaken by licensee.

The photo at the right shows a cloud seeding generator at the top of the China Peak Ski Lift near Huntington Lake.

Photo courtesy of North American Weather Consultants.

TABLE 3. SUMMARY OF PROJECT OPERATIONS IN CALIFORNIA
OCTOBER 1, 1965 - SEPTEMBER 30, 1966

Project Number (a)	Number of Generators	Silver Iodide Use (grams per hour per generator)		Total Silver Iodide Dispersed (grams)		Total Generator Hours	
		Ground Generators	Aircraft	Ground Generators	Aircraft	Ground Generators	Aircraft
12-66-1	--	----	42.5	----	---	----	100.0
14-66-1	12	6.0	----	22,581	---	3,763.5	---
14-66-2	14	6.0	----	8,216	---	1,369.2	---
18-66-1	16	6.0	----	----	---	1,294.0	---
21-66-1	30	12.0	----	20,521	695	1,710.1	24.9
21-66-2	--	----	----	----	2,280	----	63.6
21-66-3	--	----	----	----	(b)	----	57.4
22-66-1	17	15.0	----	15,225	---	1,015.0	---
23-66-1	6	25.4	----	57,855	---	2,277	---
26-66-1	20	25.0	----	----	---	1,853.5	---
27-66-1(c)	--	----	----	----	---	----	---
					Total	13,282.3	245.9

(a) First number indicates license number; second - the water year; third - numerical sequence of projects undertaken by a licensee.
(b) Licensee dispersed 213 pounds of Dry Ice (CO_2 crystals) and 160 grams of silver iodide.
(c) Licensee used electric discharge method.

Kings River
Watershed

Photo
Courtesy of
Atmospherics
Incorporated

CHAPTER II. WEATHER MODIFICATION PROJECTS

During the 1965-66 water year, the Department of Water Resources issued 13 weather modification licenses. Eight licensees conducted 11 projects during this period. Information submitted to the Department on the projects varied from minimum data required by state law to detailed project completion and evaluation reports. These detailed reports, in addition to daily logs, included descriptions of storms, physical features of target areas, equipment, and methods of evaluation; and photographs, charts, graphs, maps, and other information of interest. The following project descriptions are presented according to data in notices of intention, and project completion and evaluation reports submitted to the Department by licensees.

Kern River Watershed Weather Modification Project (12-66-1)*

Between November 13, 1965, and April 18, 1966, Precipitation Control Company of California, holder of License No. 12, conducted weather modification project operations for the County of Kern. This project was conducted to increase stream flow in the Kern River watershed.

Project equipment included a Cessna 310 aircraft dispersing silver iodide at a rate of approximately 1.5 ounces per hour. The aircraft was operated for 100 hours during 50 flights, compared to 100 hours logged during 48 flights in the 1964-65 season. Heaviest seeding occurred during November, when 29.4 hours were logged during 14 flights, and in February, when 24.5 hours were logged during 12 flights. The remaining months of the project averaged six flights each, with hours of operation ranging from 13 hours in December to about 8 hours in March.

In addition to the usual completion report, the licensee submitted aerial photographs of seeding operations to the Department.

Upper San Joaquin River Basin Weather Modification Project (14-66-1)

Between October 14, 1965, and August 16, 1966, North American Weather Consultants of California, holder of License No. 14, conducted weather modification project operations for the Southern California Edison Company. This project was conducted to increase snowpack. Equipment was operated in the vicinity of Mammoth Pool, Huntington Lake, Shaver Lake, Florence Lake, Lake Thomas A. Edison, and Kaiser Pass and adjacent foothill areas in the counties of Fresno and Madera. The target area was the drainage area of the upper San Joaquin River and its tributaries in the County of Fresno. The basin of the San Joaquin River above Power House No. 8 and adjacent foothills were also possibly affected by the project.

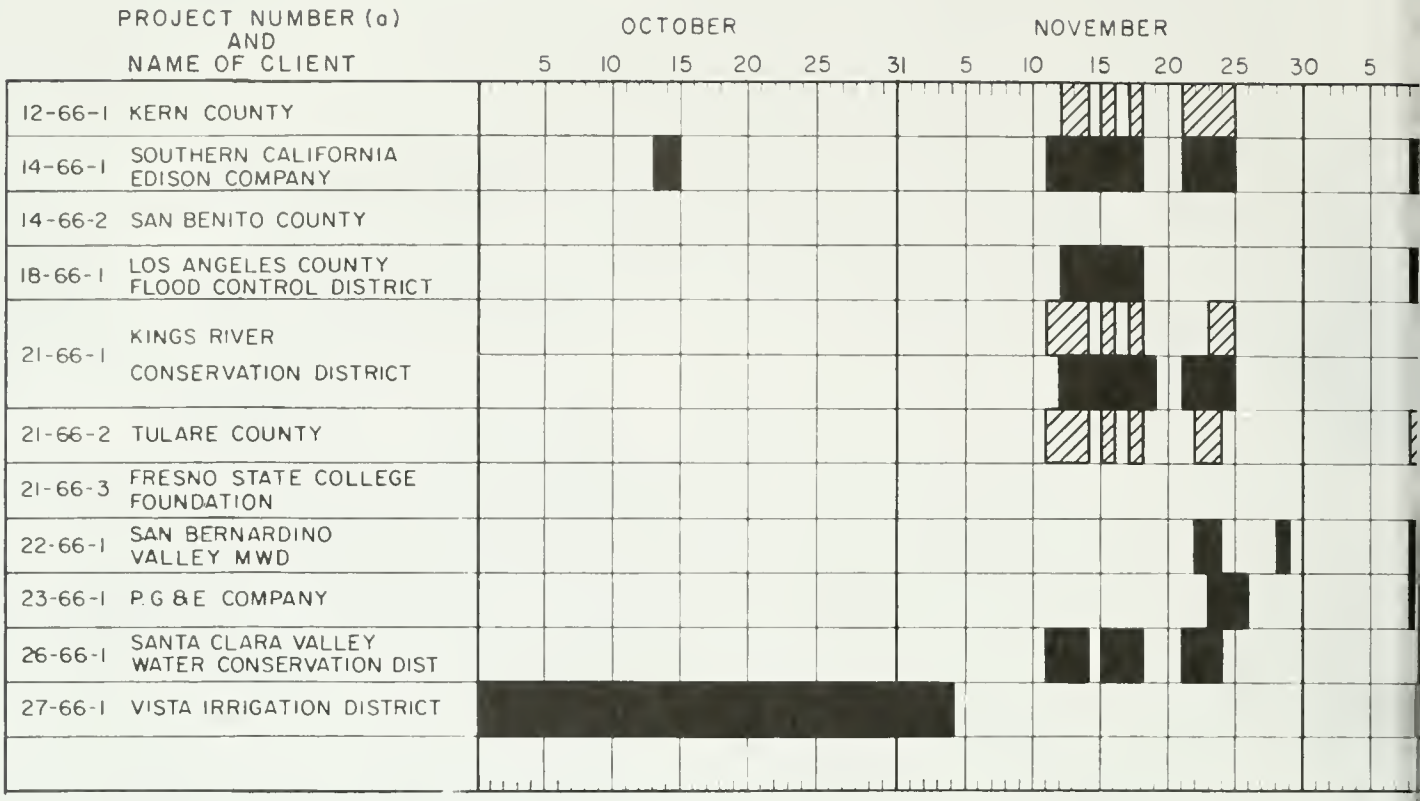
Project equipment included twelve ground-based generators. Seven generators were located in the southern and southwestern portions of the target area, and five generators outside the target area and to the southwest. Target area and generator locations are shown in Figure 6.

The ground generators were operated for 3,763.5 hours over a period of eleven months, contrasted to 4,612.8 hours of operation logged during the 1964-65 season over a period of ten months. Heaviest seeding took place in November and December, when 1,394 hours and 789.5 hours, respectively, were logged. Lightest seeding took place in October, and during the summer months of July and August. In each of these three months, less than 100 hours of seeding took place.

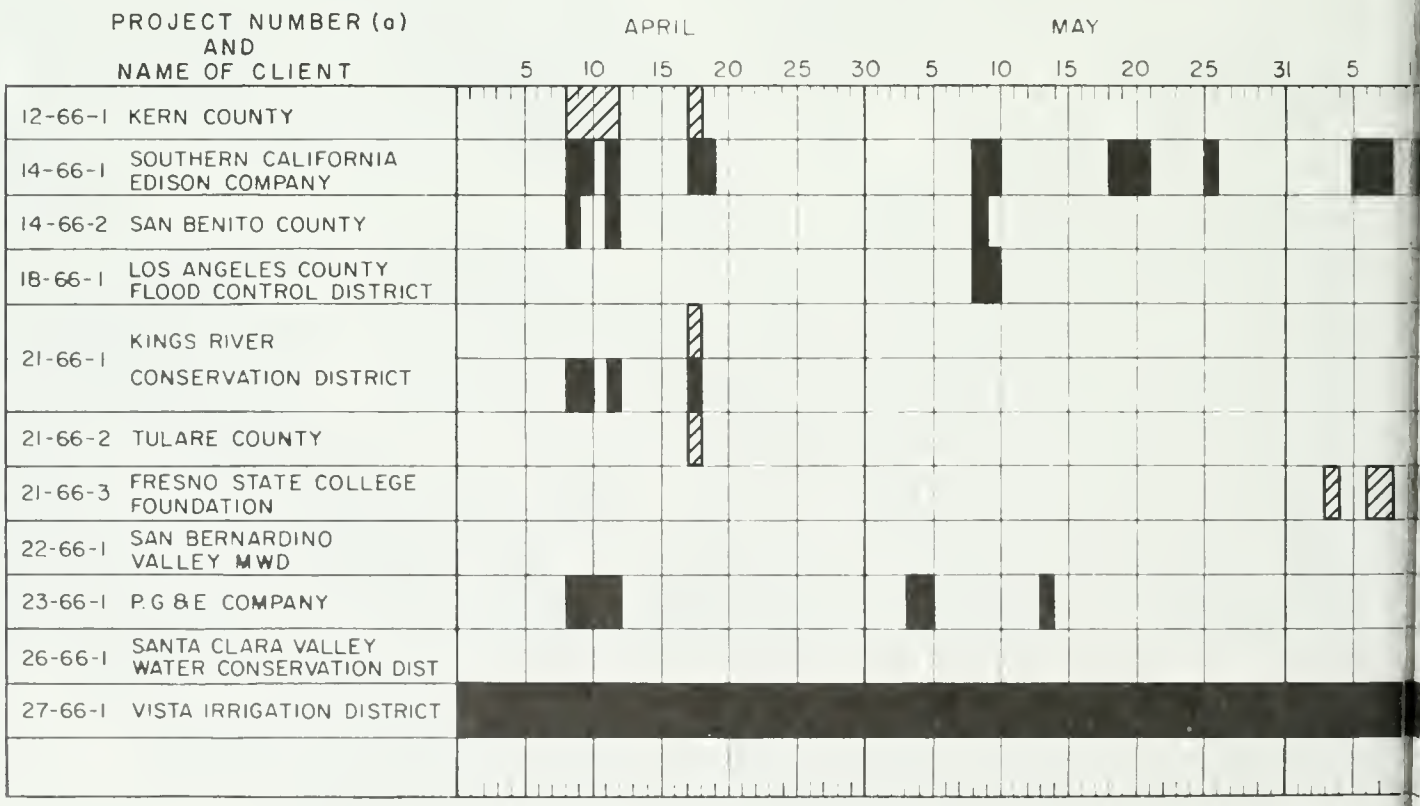
Operations were carried out during forty storms. Of these, four or five storms occurred each month from November through June. A total of six additional storms occurred during October, July, and August.

The ground generators emitted silver iodide at the rate of six grams per hour

* Project Number

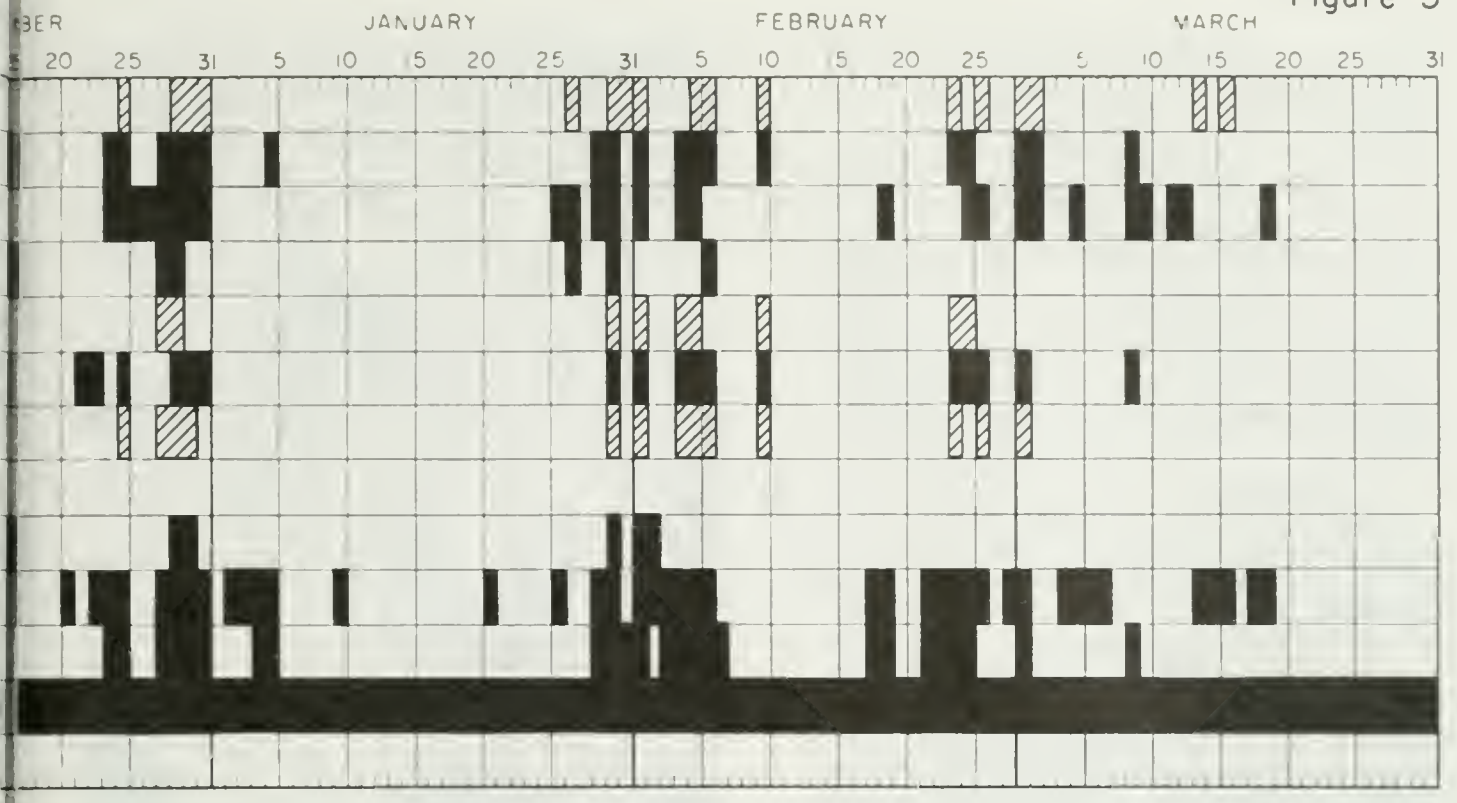


1965

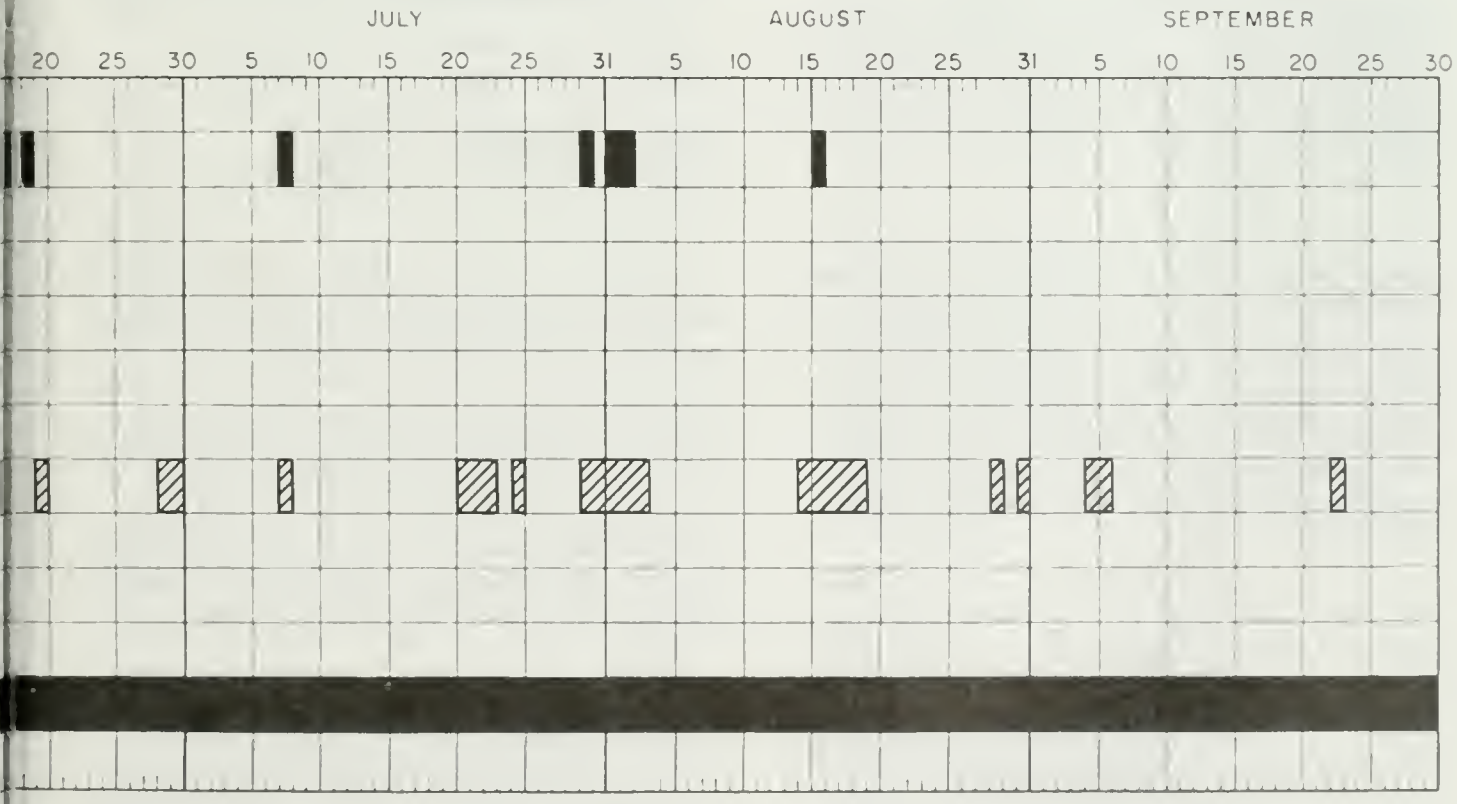


(a) Project number consists of three parts: first part indicates license number, second – the water year; and third – numerical sequence of projects undertaken by a licensee.

Figure 5



1966



1966

WEATHER MODIFICATION OPERATIONS IN CALIFORNIA

DAYS OF CLOUD SEEDING

OCTOBER 1965 THROUGH SEPTEMBER 1966

T

BASED GENERATORS

Figure 6. Target Area and Generator Locations, Upper San Joaquin River Basin Project

per generator, compared to the rate of 6.7 grams per hour per generator for the 1964-65 season. A total of 22,581 grams of silver iodide was dispersed during the project in the 1965-66 season. A radio-controlled generator near Mt. Given is shown on Figure 7.

A paper concerning the project, "Fifteen Years' Experience with Weather Modification in the Southern Sierra Nevada", was presented by R. D. Elliott, President of North American Weather Consultants, and W.A. Lang, Chief Hydrographer, Southern California Edison Company, at the American Society of Civil Engineers -- Irrigation and Drainage meeting, held on November 4, 1966.

Figure 7. Radio-Controlled Generators Near Mt. Given

Photo courtesy of North American Weather Consultants

San Benito County Weather Modification Project (14-66-2)

Between December 24, 1965, and May 9, 1966, North American Weather Consultants of California, holder of License No. 14, conducted weather modification project operations for San Benito County. This project was conducted to increase precipitation in the County. Equipment was operated in the Counties of Monterey and San Benito. The project affected areas only within San Benito County.

Project equipment included fourteen ground-based generators. Six generators were located within the target area. Eight generators were located outside the target area, to the south and southwest. Target area and generator locations for this project are shown in Figure 8.

The ground generators were operated for 1,369.25 hours over a period of six months, compared to 1,522.5 hours of operation logged during the 1964-65 season over a period of four months. Heaviest seeding took place in December,

Figure 8. Target Area and Generator Locations, San Benito Project

when the generators were operated for 543 hours. Lightest seeding took place in April and May, when 54.5 hours and 10.5 hours, respectively, were logged.

Operations were carried out during 18 storms. Four storms each occurred during December and February, and five storms in March. The months of January, April, and May contained a total of five storms.

The ground generators emitted silver iodide at the rate of six grams per hour per generator, compared to 6.7 grams per hour per generator for the 1964-65 season. A total of 8,215.5 grams of silver iodide was dispersed during the project in the 1965-66 season.

Artificial Nucleation Program in the San Gabriel River, Big Tujunga, and Pacoima Drainage Basins (18-66-1)

Between November 13, 1965, and May 9, 1966, the Los Angeles County Flood Control District, holder of License No. 18, conducted weather modification project operations on its own behalf. This project was conducted to increase precipitation at certain locations in the San Gabriel Mountains. Equipment was operated in areas adjacent to the drainage areas tributary to District-owned dams. The target area was located in the San Gabriel Mountains and adjacent to the District-owned dams, extending from Pacoima Dam on the west to Thompson Creek Dam on the east. Mountainous areas lying generally northward from the southern foothills of the San Gabriel Mountains between the City of San Fernando and the City of Claremont were possibly affected by the project.

Project equipment included 16 ground-based generators burning a 2% solution of silver iodide. The generators were located mainly to the south of the target area. An analysis of seeding during the 1964-65 season prepared by North American Weather Consultants indicated that seeding produced no effect over the northeast portion of the target area. It was suggested, on the basis of this analysis, that more low-level westward drift of nucleation agent than expected had occurred. To compensate for this drift, generators at Baldy Guard Station and Thompson Creek Dam, both located southeast of the target area, were used more extensively during the 1965-66 season than during previous years. Target area and generator locations for this project are shown on Figure 9.

The ground generators were operated for 1,292.25 hours over a period of seven months, compared to 1,270.8 hours of operation logged during the 1964-65 season over a period of six months. Heaviest seeding took place in November and December, when 876 hours and 195.75 hours, respectively -- 83% of the season's total -- were logged. No seeding took place during March and April.

There were three periods of heavy precipitation during November and December. The first storm period, occurring November 13-18, was seeded. The second period, occurring November 22-25, was not seeded because an increase in precipitation was not wanted at that time. The third major period, occurring December

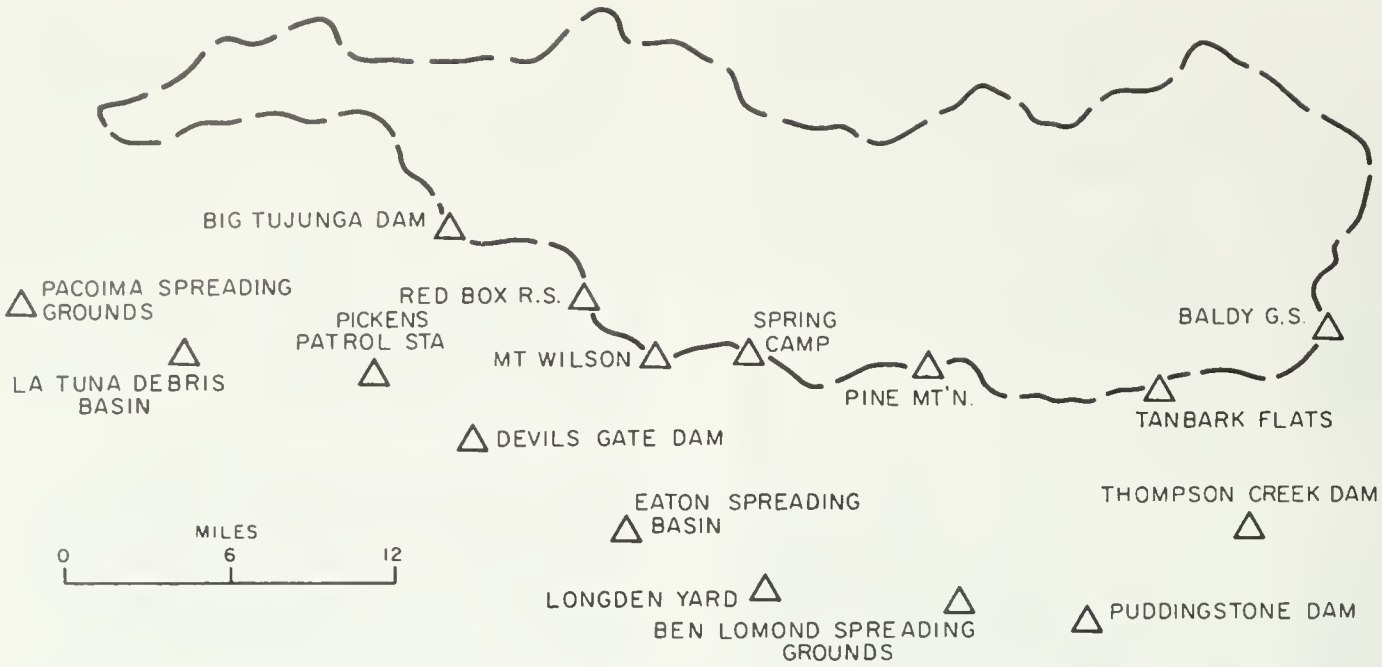


Figure 9. Target Area and Generator Locations for San Gabriel River, Big Tujunga, and Pacoima Drainage Basin Program

29, was seeded, an increase in precipitation having again become desirable by December 9, when a weaker system was seeded. There were a few storm systems after December. These, however, were weak and short, and had little precipitation.

The generators emitted silver iodide at the rate of six grams per hour. A total of about 7,770 grams of silver iodide was dispersed during the 1965-66 season.

It was not found feasible to continue to use the evaluation procedure employed during previous season. This procedure depended on data obtained by frequent sampling of air mass parameters by rawinsondes released from Santa Monica. These data were no longer available, due to the reduction of the operations of the Santa Monica Rawinsonde Station.

The procedure followed in the evaluation for the 1965-66 season, as outlined in a report prepared by North American Weather Consultants, focuses attention on the peak precipitation period during historical non-seeded periods and during 1965-66 seeded periods. A peak precipitation period was designated as the seven-hour period beginning with the third hour prior to the hour of peak precipitation. Analyses were made using the total precipitation during the seven-hour periods for the seeded and non-seeded cases selected. Analyses were also made using the average of precipitation amounts for each hour of the seven-hour periods selected. A statistical test can be applied to determine the significance of indicated excesses during peak precipitation periods. These peak periods were related to storm total precipitation, and an estimate was made of the amount of precipitation due to seeding during the 1965-66 season.

For the 1965-66 evaluation, seven storm periods were selected, with hourly data for ten stations. The total precipitation during the seven-hour periods for the seeded and non-seeded cases was compared in two ways. In the first, the peak hour was considered the hour when peak precipitation occurred in the center of the target area. In the second, the peak hour was individually selected for each station. The latter procedure

was expected to eliminate bias due to differing orientation and rate of movement of the precipitation bands.

The best estimate of the 1965-66 seeding operations indicates that the greatest effect from seeding -- a precipitation increase of over 25% -- occurred over the interior valley and front slope of the back range of the San Gabriel mountains. The type of analysis used in obtaining these estimates does not, however, permit the application of a statistical test to determine the statistical significance of the estimated precipitation increase.

In addition to the usual completion report, the Los Angeles County Flood Control District submitted to the Department a report prepared by North American Weather Consultants entitled, "Analysis of an Artificial Nucleation Program in the San Gabriel River, Big Tujunga, and Pacoima Drainage Basins (Report No. 6-84)", and a project evaluation statement.

Kings River Weather Modification Program (21-66-1)

Between November 13, 1965, and April 21, 1966, Atmospherics Incorporated, holder of License No. 21, conducted weather modification project operations for the Kings River Conservation District. This project was conducted to increase precipitation. Equipment was operated in parts of Fresno, Kings, Tulare, and Inyo Counties, and the target area was the Kings River watershed above Pine Flat Reservoir. In addition to the target area, parts of Fresno and Tulare Counties, which include the Kings River and certain tributary streams above Pine Flat Reservoir, were possibly affected by the project.

Project equipment included 30 modified Wells-Fuquay aspirator-type propane ground generators burning a 2% solution of silver iodide in acetone at about 1800° F at a rate of 12 grams of silver iodide per hour per generator. About 10^{15} nuclei per gram of silver iodide were produced. Propane pressure was set at 10 pounds per square inch through a #60 standard gas orifice, with a resultant use rate of approximately 0.7 gallons per hour.

Only minor adjustments were made in the generator locations established during the 1964-65 season. Generator units in the northern portions of the target area were placed at Wishon Dam, Balch Camp, Watts Valley, and Piedra. Those along the southern boundary of the target area -- the main line of generators -- were located on Highway 180 from the Friant-Kern Canal crossing to Cherry Gap, which is slightly over 6,000 feet in elevation. Other generators were placed in the Hills Valley-Badger-Pinehurst area.

The terrain of the Kings River watershed makes difficult the positioning of ground generators in a manner providing complete nuclei coverage of the target area. This operational difficulty, together with the occurrence of rapid cloud developments and fast-moving storms, was partially overcome by means of seeding from an aircraft. A twin-engine Piper Apache aircraft equipped with superchargers and de-icing equipment for high-altitude all-weather flying was used for seeding operations. Aircraft seeding flights were generally conducted at the -5° C level.

Monitoring equipment comprised a mobile radar unit -- also used for research purposes -- installed about 14 miles ENE of Fresno. This field headquarters, at an elevation of 350 feet above sea level, provided a view of the entire Kings River watershed. All storms approaching the Fresno area from the west were observed and tracked into the higher mountain country to the east.

The radar unit operated on a frequency of 9,400 megacycles with a peak power of 50,000 watts. It had a maximum range of 200 miles, with steps of 10, 20, 80, and 200 miles. The system included two 7"

Plan Position Indicators. One indicator was used for general viewing and the other, for time-lapse photography. A radio communications network operating on a frequency of 151.625 megacycles was also used for the project.

In addition, a network of small rain gages was placed along Highway 180 at elevations between 600 and 5,200 feet. Rainfall totals were collected after each storm period, and monthly totals were compiled.

Ground generators were operated for a total of 1,710.1 hours over a period of six months, contrasted to 1,964.3 hours logged over a period of six months during the 1964-65 season. The generators dispersed 20,521 grams of silver iodide. The aircraft was operated for 24.9 hours during 24 flights, in contrast to 51.5 hours logged in 54 flights during the 1964-65 season. In addition, 14 flights were made for research purposes. A total of 695 grams of silver iodide was dispersed from the aircraft from newly developed pyrotechnic units. Twenty storms -- of which 19 were seedable -- moved through or affected the target area during the period of operations.

Four storms moved through the project target area during November. All of these storms produced moderate to heavy amounts of precipitation throughout the Kings River watershed and were well suited for cloud seeding efforts. Thirty-four ground generators were operated for a total of 709.9 hours during these storm periods. This is about four times the average generator hours normally logged in November. The aircraft made nine seeding flights along the southwest portion of the target area. Clouds were of a type which responded well to seeding.

Four storms also moved through the target area in December. Two were very well suited for seeding, and two were considered marginal types. Twenty-three ground generators were operated for a total of 404.8 hours during the four storm periods. The aircraft made three seeding flights.

One storm moved through the target area in January. Four ground generators were operated for a total of 38.7 hours. The aircraft made two seeding flights.

During February, five storm systems passed through the target area. Each storm period was light in intensity, and seeding was considered marginal in two of them. Twenty ground generators were operated for a total of 383.1 hours during the five storm periods. The aircraft made seven seeding flights.

Three very weak storm systems affected the target area in March. Two were considered marginal for seeding and the third, unsuitable. Eleven ground generators were operated a total of 31.5 hours. No seeding flights were made.

During April, three storm systems moved through the target area. Two were very marginal types, but the third was well suited for seeding. Ground generators were ignited during all three storm periods, for a total of 142.1 hours. The aircraft made two seeding flights during the third storm period.

During the 1965-66 season, Atmospherics Incorporated continued research efforts in the Southern Sierra under a cost-sharing contract with the National Science Foundation. The main portion of the National Science Foundation grant was used for additional instrumentation, with the object of providing a better understanding of precipitation mechanisms and their relation to the cloud seeding operations. This basic research effort included study of wind profiles, temperature gradients, ice nuclei distribution, snow crystal types, electrical effects, and condensation nuclei distribution. Water sample studies and radar analyses were made.

According to an evaluation of the project by Atmospherics Incorporated, a statistical analysis of 1965-66 streamflow figures as given by the U. S. Geological Survey indicates an increase of slightly over 159,000 acre-feet -- about 15% over

the expected total -- due to cloud seeding. The Merced River measured at Pohono Bridge and the Kern River measured near Kernville together with #3 Canal were used as control streams. Cloud seeding over the Kaweah and Tule Rivers may have had some effect on the upper Kern River, modifying the flow of this southern control stream.

Evaluations were made each year of the twelve-year period of the weather modification program. According to these evaluations, cloud seeding produced a total apparent increase of 921,170 acre-feet in Kings River flow, an average increase of 76,760 acre-feet yearly.

In addition to the usual completion report, Atmospherics Incorporated submitted to the Department an evaluation report entitled, "Cloud Seeding on the Kings River Watershed: Final Report on the 1965-66 Season with Review of Results for Water Years 1955-65".

Tulare County Weather Modification Project (21-66-2)

Between November 12, 1965, and April 18, 1966, Atmospherics Incorpirated, holder of License No. 21, conducted weather modification project operations for the County of Tulare. This project was conducted to increase precipitation in a portion of Tulare County. The project area is bounded on the north by the Kings River drainage between the junction of Cover Road and Highway 180, and Triple Divide Peak; on the east by the western drainage boundary of Kern River; on the south by the Tulare County line; and on the west, by Highway 65 to its junction with Highway 198, and an imaginary line north from this point to the junction of Cover Road and Highway 180. Equipment was operated in parts of Fresno, Tulare, Kings, Kern, and Inyo Counties.

Project equipment comprised a twin-engine Piper Apache aircraft equipped with turbochargers and de-icing equipment for high-altitude all-weather flying. The mobile radar system used in the Kings River Weather Modification Project was, when not specifically operated for that project, employed to observe precipitation areas in the Tulare County target area.

The aircraft was operated for 63.6 hours during 34 flights. A total of 2,280 grams of silver iodide was dispersed.

Nineteen storms moved through or affected the target area during the period of project operations. Below-normal precipitation occurred January through April.

Four storm periods affected the target area in November. All were well suited for seeding. Precipitation totals of as much as five inches were recorded at foothill and mountain stations. The aircraft made eleven seeding flights, a total of 18.5 hours of operation.

During December five storm systems moved through the target area or affected it. Two were very well suited for seeding. The ramining three were considered marginal types. However, four of the storms were seeded, the aircraft making eight flights during 18.5 hours of operation.

In January one storm moved through the target area, depositing below-normal amounts of precipitation. Two flights were made along the western sections of the target area. A total of 5.2 hours was logged.

Five storm systems affected the target area or passed through it in February. Four of these storms were of light intensity, resulting in below-normal precipitation for the month. However, all five storm systems were seeded. The aircraft logged 17.7 hours in ten seeding flights.

During March, three very weak storm systems had only slight effects in the Tulare target area. The San Joaquin Valley experienced the driest March since the 1930's, only 0.01 inch of rain falling in the Fresno area. Only the final storm was seeded. Marginal conditions limited seeding to one flight of 0.6 hours.

One storm, producing more than an inch of precipitation at some foothill and higher mountain stations, passed through the target area in April. Two aircraft flights, totaling 3.1 hours, were made.

A portion of the research effort, conducted by Atmospherics Incorporated under a National Science Foundation grant, took place in the Kaweah, Tule, and Kern watersheds.

Project Orographic Cumulus (21-66-3)

Between June 4 and September 23, 1966, Atmospherics Incorporated, holder of License No. 21, conducted weather modification project operations on behalf of Fresno State College Foundation. This project was conducted as an applied research effort on orographic cumulus clouds. Equipment was operated in parts of Fresno, Tulare, Kings, Kern, and Inyo Counties.

The target area included the Kings River watershed above Pine Flat Reservoir and an area delimited on the north by the southern boundary of the Kings River drainage; on the east, by the eastern border of the Kern River drainage between Junction Peak and the Tulare County line; on the south, by the Tulare County line from a point east of Lamont Peak to the junction of the line with Highway 65; and on the west, by Highway 65 to its junction with Highway 198, and by an imaginary line from this point to the junction of Cove Avenue and Highway 180.

During the first year of the project, 213 pounds of Dry Ice (CO_2 crystals) were aerially dispersed. An aircraft was operated for 57.4 hours during 30 flights. On one flight, 160 grams of silver iodide were dispersed in experimental pyrotechnic seeding.

A sample of data collected during the project is shown on the tabulation below.

PROJECT OROGRAPHIC CUMULUS, CLOUD AND PRECIPITATION DATA (TEST CASES)

Test Case	Seed Area (Random)	Cloud Base Elevation, msl (feet)	Cloud Base Temp (°C)	Cloud Top Elevation, msl (feet)	Cloud Top Temp (°C)	Cloud Depth (feet)	Amount of CO_2 (lbs)	Vertical Growth of Seeded Cloud	Precipitation Seeded Cloud*	Precipitation Control Cloud
1	South	16,500	-4	21,300	-14	4,800	40	Yes	No	No
2	South	18,000	-7	20,100	-11	2,100	64	No	Yes	No
3	South	18,000	-8	22,100	-14	4,000	80	Yes	Yes+	No
4	North	14,500	3.5	19,000	-8	4,500	72	Yes	Yes	No
5	South	15,000	0	18,500	-10	3,500	80	Yes	No	No
6	North	12,000	8	22,000	-10	10,000	35	Yes	Yes+	Yes
7	North	12,000	4.5	16,500	0	4,500	35	Yes	No	No
8	North	10,000	11	16,000	-1	6,000	35	Yes	Yes+	No
9	South	12,000	8	24,000	-15	12,000	15	Yes	Yes+	No
10	South	14,000	-2	22,000	-12	8,000	16	Yes	Yes+	No
11	South	14,000	4	18,500	-7	4,500	30	Yes	No	No
12	South	15,000	0	18,500	-6	3,500	20	Yes	Yes	No
13	North	15,500	1	20,000	-10	4,500	30	Yes	No	No
14	South	15,000	1	19,000	-8	4,000	35	Yes	No	No
15	South	14,500	2	23,000	-16	8,500	50	Yes	Yes+	Yes
16	South	13,000	6	21,000	-14	8,000	36	Yes	Yes+	No
17	North	12,500	5	19,000	-8.5	6,500	18	Yes	Yes+	No
18	North	12,000	0	18,000	-14	6,000	24	Yes	Yes	No
19	North	13,000	-3	21,000	-20	8,000	32	Yes	Yes+	No
20	South	13,000	4	21,000	-13	8,000	8	No	No	No
						Total	755			

* Yes+ indicates that precipitation reached the ground. Seven seedings resulted in no precipitation, nine resulted in precipitation that reached the ground, and four resulted in precipitation that did not reach the ground.

Upper Santa Ana River Watershed Weather Modification Project (22-66-1)

Between November 23, 1965, and February 2, 1966, San Bernardino Valley Municipal Water District, holder of License No. 22, conducted weather modification project operations on its own behalf. This project was conducted to increase precipitation in the upper Santa Ana River Watershed. The target area comprises approximately that portion of the upper Santa Ana River Watershed within San Bernardino County. The target area contains about 576,000 acres, and approximately 80% of this area lies within the San Bernardino National Forest.

About half of the target area is over 3,000 feet in elevation. The northern portion of the area, bounded by the San Bernardino mountains, reaches elevations of more than 5,000 feet. The southwest corner of the target area has an elevation of less than 1,000 feet. Most of the eastern portion of the target area lies above the 3,000-foot level, containing areas more than 8,000 feet in elevation. The Santa Ana River and its tributaries, Mill Creek and City Creek, lie in the eastern portion of the target area.

Equipment was operated primarily in the southern portion of San Bernardino County and the western portion of Riverside County. No effect on any area outside the target area was foreseen. Project equipment included 17 ground-based generators burning a silver iodide solution. Seven generators were located in the northeastern portion of the target area, three in the southwestern portion, and one at Cajon in the northwestern portion. The remaining six generators were placed at locations outside the target area and to the southwest.

Monitoring equipment included a radar station at Box Springs Mountain, outside the target area. Target area and locations of generators are shown on Figure 10.

Figure 10. Target Area and Generator Locations, Upper Santa Ana River Watershed Project

The ground generators were operated for 1,015 hours over a period of four months, contrasted to 2,366.7 hours logged over a period of six months during the 1964-65 season. Heaviest seeding occurred during December, when 711.75 hours -- about 70% of the season's total -- were logged. Lightest seeding occurred in February, when only 69.75 hours were logged. During March and April the project was not operated. By contrast, 40% of the total generator-hours for the 1964-65 season were logged during these months.

Six storms occurred during the period of operations, three in December and one each for the remaining months.

A total of 15,225 grams of silver iodide was dispersed during the project.

Lake Almanor Cloud Seeding Project (23-66-1)

Between November 24, 1965, and May 14, 1966, the Pacific Gas and Electric Company, holder of License No. 23, conducted weather modification project operations on its own behalf. This project was conducted to gather information on the effectiveness of cloud seeding. Equipment was operated in Plumas, Lassen, and Tehama Counties. The target area was the drainage basin of Lake Almanor, Butt Valley Reservoir, and Mountain Meadows Reservoir in the Northern Sierra Nevada Mountains. Areas in the counties of Plumas, Lassen, Shasta, and Tehama were also possibly affected by the project.

Project equipment included six radio-controlled generators placed on peaks and ridges above 6,000 feet in elevation. Because valley locations in mountainous areas are often subjected to inversions and local channelling, the high-elevation location of generators permitted more accurate estimates of plume trajectories. The generators released silver iodide crystals which act as ice nuclei at temperatures below -5° C. Target area and locations of generators are shown on Figure 11.

Monitoring equipment included a network of 51 weighting-type precipitation gages. The orifice of each gage was heated with a small propane flame to prevent snow from sticking or capping the gage. Wind measurements for diffusion estimate and trajectory analysis were accomplished through observation of radar tracks of targets and movement of radar precipitation echoes, and use of a heated wind vane at 7,500 feet.

The generators were operated for 2,277 hours over a period of seven months, contrasted to 1,248.5 hours logged during the same period in the 1964-65 season. Heaviest seeding -- a total of 1,507 hours, or about 66% of the seasonal total -- occurred in December, February, and March, when 506 hours, 561 hours, and 440 hours, respectively, were logged. Lightest seeding occurred in May, when 88 hours were logged.

A total of 70 storms occurred during the period of project operations. From December through March, between 12 and 17 storms occurred each month. November, April, and May each experienced five or fewer storms.

A total of 57,855 grams of silver iodide was dispersed during the project.

Figure 11. Target Area and Generator Locations, Lake Almanor Project

This project constitutes the fourth year of a five-year test program. The Pacific Gas and Electric Company will evaluate the completed program. Additional information concerning the Lake Almanor Cloud Seeding Project may be found in "Human Dimensions of Weather Modification" (edited by W. R. Derrick Sewell), in an article by Donald Eberly entitled,"Weather Modification and the Operations of an Electric Power Utility: The Pacific Gas and Electric Company's Test Program."

Santa Clara Valley Cloud Seeding Project (26-66-1)

Between November 12, 1965, and March 19, 1966, Santa Clara Valley Water Conservation District conducted weather modification project operations on its own behalf. In previous seasons, the project was conducted for the District by the Weather Modification Company. However, in 1965 the District purchased the equipment of the Weather Modification Company and began operation of the project itself.

The project was conducted to regulate precipitation in parts of the County of Santa Clara. Equipment was operated in Santa Clara, San Mateo, Santa Cruz, Monterey, and San Benito Counties. Areas adjacent to the target area which were possibly affected by the project were parts of Alameda, San Mateo, Santa Cruz, Monterey, San Benito, Merced, Stanislaus, and San Joaquin Counties.

Project equipment included 20 ground-based generators of the Modified Starfire type. These generators burned a 2.75% solution of silver iodide at a rate of approximately 25 grams per hour per generator, one gram producing more than a quadrillion nuclei. The generators were usually located to the windward side of the crest of the Santa Cruz Mountains, or near the crest. Positioning generators in this way permitted silver iodide particles to be carried upward by rising air currents. When the particles reached an altitude at which the temperature was -5° C, they began to provide nuclei for ice crystals, which were carried over the watershed area of the Santa Clara Valley.

In previous seasons, an aircraft was used to seed areas of the valley poorly accessible from ground generators. However, technical difficulties occurred in the use of both a modified airborne propane-burning generator and silver iodide impregnated flares. In addition, it became extremely difficult to get clearance for flights during storms because the seeding flight path lay along the main San Francisco-Los Angeles commercial airline route. Thus, it was decided to suspend aircraft activity temporarily. No seeding flights were made during the 1965-66 season.

A trailer coach on Canoas Hill at the Santa Clara County Communications Center served as operational headquarters. Monitoring equipment included a General Electric SNB13 weather radar set, a facsimile machine linked to the U. S. Weather Bureau circuit for weather maps, a low-frequency radio for hourly weather data, and a microbarograph. A 16 millimeter motion picture camera was used for time-lapse photography of the radar scope during seeding. All operations for the 1965-66 season were recorded on film.

The ground generators were operated for 1,853.5 hours over a period of five months, compared to 1,876.8 hours logged over the same period during the 1964-65 season. Lightest seeding took place in March, when 23.25 hours were logged. Monthly totals for November through February ranged from 541 hours to about 346 hours. A total of 46,337.5 grams of silver iodide was dispersed.

The project will be evaluated in accordance with the target-control method. Two areas are selected for use in this type of evaluation. One, the target area, is seeded. The second, the control area, is an area which is near the target, but situated so that it will not be affected by seeding. Precipitation data from 17 control stations and 25 target area sta-

tions are being used in evaluating the project. Average normal rainfall, based on the period 1944 to 1954, was calculated for both control and target stations. A comparison of normal average target rainfall and normal average control rainfall indicated a target-control ratio. Multiplying the average seasonal accumulation of precipitation for the control stations by this ratio, an estimate can be made of average accumulation in the target area without seeding. Any recorded precipitation in the target area in excess of this amount is considered to have been induced by seeding.

In early 1965, a limited amount of seeding was conducted in San Benito County. During the 1965-66 season, however, the target area was enlarged to include all of San Benito County. Five of the southern control stations were included in this seeded area. The project was not yet evaluated for the 1965-66 season, the effect of this circumstance on the evaluation procedure not having been determined.

In addition to the usual completion reports, the Santa Clara Valley Water Conservation District submitted to the Department an analysis of the project entitled, "Report, 1965-66 Season: Santa Clara Valley Cloud Seeding Project."

Artificial Modification of Atmospheric Space Charge at Warner Ranch (27-66-1)

Between October 1, 1965, and September 30, 1966, Vista Irrigation District, holder of License No. 27, conducted weather modification project operations on its own behalf. This project is part of a three-year experimental effort in Lake Henshaw Basin. Equipment was operated in the area adjacent to Henshaw Dam in San Diego County. An area adjacent to the target area which was possibly affected by the project was Warner Ranch in the County.

The electric discharge method was used for the project. Project equipment included two stainless steel wires -- each 0.010 inch in diameter -- supported on plastic insulators erected on steel poles placed along the crest of Henshaw Dam. From the dam, the line extended southward supported by wooden poles. The line had a total length of approximately 5,500 feet. It was energized at a maximum voltage of 50 kilovolts direct current by a power supply located at the dam. A corona-effect discharge of ions, which acted as a nucleation agent, was produced.

The power supply was provided with automatic over-current and over-voltage protection, metering equipment, and a running-time recorder. Weather instrumentation was installed at the power supply location.

This experimental effort is to continue for a minimum of two years. Its objectives are:

1. To measure the vertical atmospheric potential gradient to the leeward of the line, both at the surface and aloft, and to correlate the effects of line voltage and current, wind velocity, temperature, and humidity on this gradient.

2. To measure precipitation on a monthly and seasonal basis both to the leeward and windward of the line, comparing this information with historical precipitation records to determine long-term effects of charge modification on precipitation.

3. To study each rain shower, correlating precipitation with potential gradient, line characteristics, and other weather conditions, to determine the factors producing the greatest probability of increasing precipitation.

4. To study the effect of altered potential gradient on evaporation losses.

5. To increase precipitation.

An evaluation of the project through computer analysis is being carried out by the New York Central Technical Research Department.

In addition to legally required minimum data, Vista Irrigation District submitted to the Department a preliminary progress report entitled, "Artificial Modification of Atmospheric Space Charge, Warner Ranch, California", together with photographs of project equipment. A photograph of emission power lines and insulators is shown on Figure 12.

Figure 12. Emission Power Line and Special Insulators Used With Electrical Discharge Method of Cloud Seeding

Photo courtesy of Vista Irrigation District

APPENDIX A

SEASONAL PRECIPITATION

Because weather modification operations in some measure reflect precipitation patterns, statewide precipitation for the 1965-66 water year is summarized below. Seasonal and monthly precipitation normals (averages) are based on the 30-year period 1931-1960.

Statewide precipitation for the 1965-66 water year was about 75 percent of normal. Water-year totals were generally near normal in the North Coastal area and well above normal (about 120 percent) south of the Tehachapi Mountains. The remaining areas of the State, however, averaged only 70 percent of normal. The extremes varied from low 46 percent of normal at Cottonwood Gates, in the Owens River Drainage of the Lahontan area, to a high of 152 percent of normal at Iron Mountain, in the Colorado Desert area. Accumulated inches of precipitation during the water year contrasted widely from a statewide low of only 2.2 inches at Death Valley to a high of 108.05 inches at Honeydew, in the Mattole River Drainage.

Precipitation in October was well below normal. Conditions changed early in November with the entrenchment of a low pressure trough off the California coast. Two major storms brought heavy precipitation to all areas of the State.

Southern California, where November totals far exceeded any previous record, was especially affected by these storms. December precipitation also was very heavy in Southern California. Of the 1966 water year total for this area, 85 to 90 percent fell during November and December. Subsequently, precipitation in Southern California returned to a more usual below-normal regime.

By December accumulated precipitation totals were above normal in all areas of the State. In January precipitation exceeded normal in the North Coastal area but was relatively light in other regions. Below normal precipitation occurred throughout California for the remainder of the water year, resulting in below-normal water-year totals in all major water-producing areas.

More detailed information on precipitation and general water conditions in California during the 1965-66 water year may be found in Department of Water Resources' Bulletin No. 120-66, "Water Conditions in California: Fall Report, October 1966".

The photo at the left shows the spectacular vertical growth of a small cumulus cloud following seeding with Dry Ice pellets. Great numbers of water droplets have changed to ice crystals, particularly in the lower levels of the cloud.

Photo courtesy of Atmospherics Incorporated.